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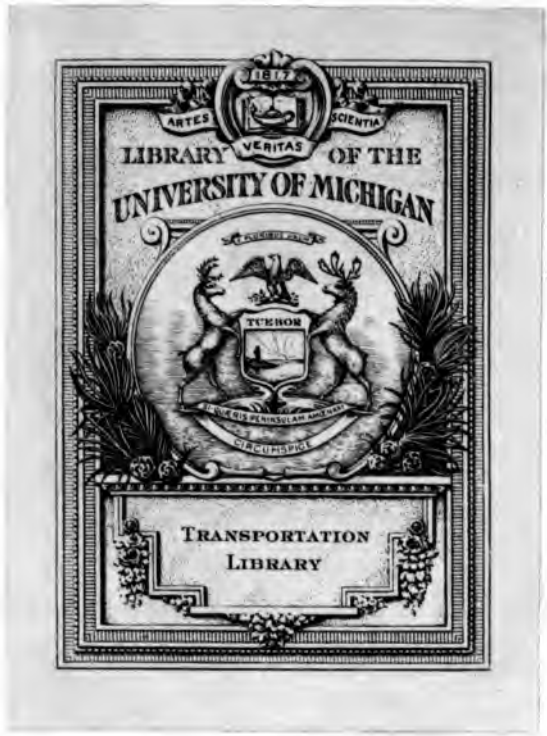
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SECOND REPORT,

&c. &c.

LONDON:
R. CLAY, PRINTER, BREAD-STREET-HILL,
DOCTORS' COMMONS.

SECOND REPORT

ADDRESSED TO

THE DIRECTORS AND PROPRIETORS

OF THE

LONDON AND BIRMINGHAM RAILWAY COMPANY,

FOUNDED ON

AN INSPECTION OF, AND EXPERIMENTS MADE ON THE LIVERPOOL AND MANCHESTER RAILWAY.

BY

PETER BARLOW, F.R.S.

COR. MEM. INST. FRANCE, OF THE IMPERIAL AND ROYAL ACADEMIES OF PETERSBURGH AND BRUSSELS, ETC.

LONDON:

B. FELLOWES, LUDGATE STREET.

1835.

ERRATA.

Page 44, fourth line from bottom, *for* on *read* in.
48, two lines from top, *for* locomotion *read* locomotive.

REPORT

ADDRESSED TO

THE DIRECTORS

OF THE

LONDON AND BIRMINGHAM RAILWAY COMPANY.

Introduction.

In presenting this Second Report to the Directors and Proprietors of the London and Birmingham Railway Company, it may be well to state the resolution of the general meeting which gave rise to it.

Extract.

"Resolved unanimously—That Mr. Barlow be requested to visit the Liverpool and Manchester Railway, to view that line, and advise this Board as to the weight of rails, the description of chairs and fastenings, the distance of the supports, and the size of the blocks that he would advise the Directors to adopt; and to accompany such advice with any observations generally on the subject."

It was accordingly arranged, conformably with this resolution, that I should visit Liverpool with the Chairman, Isaac Solly, Esq., and Thomas Tooke, Esq. one of the London Directors, and there meet T. W. Rathborn, Esq., and Edward Cropper, Esq., two of the Liverpool Directors; that they should accompany me in my inspection, and while making such experiments as that inspection might render desirable;—the Liverpool and Manchester Directors, on their part, most handsomely offering every assistance and facility in their power, by placing at the disposal of the deputation the Swiftsure locomotive engine, with such carriages as might be required for our purpose, and every other accommodation we might desire.

We met, as appointed, at the Liverpool station of the Liverpool and Manchester line, and employed the first day in examining the state of the rails, chairs, and blocks, modes of fixing, and other particulars. In the course of this examination, I took the opportunity of inquiring on the spot the opinion of the resident engineers, contractors for repairs, workmen, and

others, relative to these several points; but I was much disappointed to find those opinions, in most instances, discordant, and in many directly contradictory; a circumstance the more remarkable, as one would have thought that five years' incessant practice would have been sufficient to eradicate many early erroneous ideas.

I am not myself a practical man, but from my situation and pursuits I have been for nearly thirty years in almost constant intercourse with two of the largest and most varied mechanical establishments in the kingdom, and have, during that time, witnessed or superintended a vast number of experiments and trials on various mechanical subjects, many of which I have afterwards been enabled to examine in the works at large; I am therefore, to a certain extent, acquainted with what theory gives, and what practice requires, and the limits it prescribes; as I am also with the views and arguments of practical men, who I know sometimes, like other persons, in their anxiety to avoid one evil lose sight of other collateral evils, which their remedy increases or creates;

but I must say that I never saw this so strongly marked as on the present occasion, nor such a diversity of conflicting opinions on what appears so simple and plain a case. This is a circumstance much to be regretted, not only as regards the doubts which it naturally throws upon the mind of proprietors, embarking large amounts of capital in the undertaking, but also in respect to practical men themselves, whose judgment must suffer depreciation by such discordance. Opinions derived from long experience are exceedingly valuable, and outweigh all others, while they are consistent with facts and with each other; but they are worse than useless when they lead, as in this instance, to directly opposite conclusions.

In making these remarks, I beg to be understood as intending no disrespect to the opinions of practical men generally, but simply to show that it was impossible, in this case, for me to be guided by them; and thereby to justify the plan I soon determined to adopt, viz. to avoid, as far as possible, argument founded on mere hypothesis, and to substitute for the latter, facts

drawn from actual experiments, which should be made publicly, registered generally, and witnessed by any one interested in the decision; and moreover, as I intended to rest my report entirely on these data, I resolved to offer no opinion, till I had time to analyze and compare my results. I am not certain that this plan of proceeding was quite what the deputation most approved, but I feel convinced that it was the only way in which justice could be done to the inquiry, and confidence obtained for the decision.

Experiments.

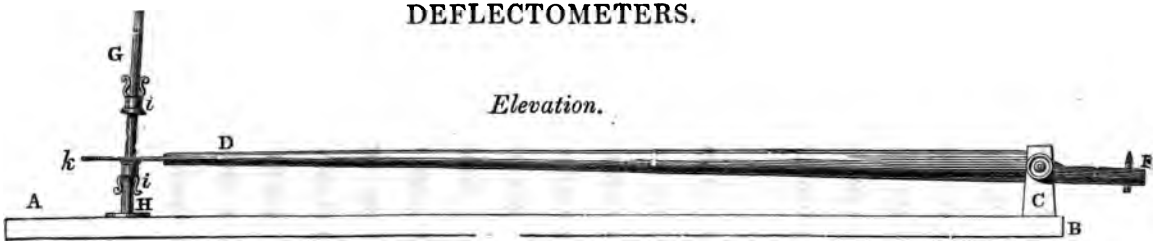
The first and most important point which required to be decided was, the strength of iron necessary to ensure the most ample safety, at any practicable speed, with any given load and given length of bearing. The strain which any quiescent load impresses on a bar, is, I think, now well known; but what is the effect of velocity? This was one of those questions on which I found opinions greatly divided; and it is a question, perhaps, considered merely

hypothetically, in which there was great room for doubt. My first object, therefore, was to reduce it to a matter of experimental fact; this rendered it necessary to construct an instrument for the purpose, and I feel myself much indebted to Mr. King, of the Liverpool Gas Works, for the ready attention he paid to my suggestions, and for the ingenuity he exercised in giving it its first form, the whole of which was left to his own invention, after being simply informed of its object, and the general mode of its intended operation.

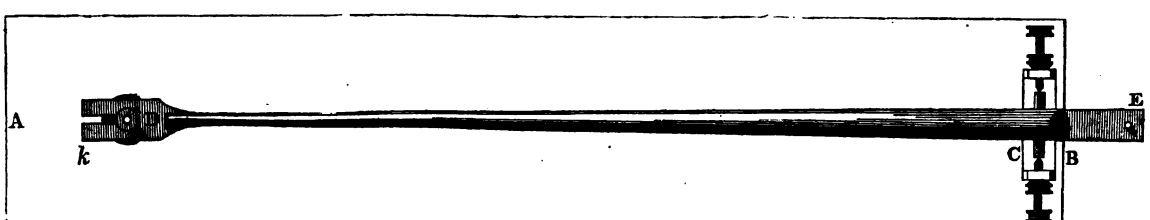
This instrument, which it is proposed to call a *deflectometer*, is represented in plan and elevation in the annexed diagram. A B is a plain board about 27 inches long and 6 inches broad, with two pillars or standards, one of which is seen in the elevation; and between them is suspended the lever D E by screw points, divided in C, in the proportion of 10 to 1; G H is a slightly inclined stout wire, on which slide the two indexes *i*, *i*, but with sufficient friction to remain in their places.

DEFLECTOMETERS.

Elevation.



Plan.



The manner of using the instrument is by levelling the ground under the centre of the rail, and placing the point E under its lower edge; the preponderance then being on the side of the long arm, the point E is kept in contact with the lower edge of the bar, and the lower index *i* is moved up to the metal plate *k*; the upper one is then, in like manner, brought down and placed in contact also. It is obvious, now, that whatever deflection the rail may sustain during the passage of an engine, or a train of waggons, the index *i* will be lifted ten times the quantity the bar is deflected, and remaining in its place, the greatest deflection the bar has sustained will be truly and distinctly indicated.

The first instrument* having been constructed, (the men working all night to finish it,) and my intention being known of using it in the morning, I was much gratified to meet on the ground, on that and the following day, several Directors and Proprietors, Engineers, and practical men interested in the inquiry. Of the former I may

* Another form of the deflectometer is given in the Appendix.

name Isaac Solly, Esq. Chairman; Messrs. Thomas Tooke, Henry Rowles, Theodore W. Rathborn, Edward Cropper, Robert Garnet, Edw. Wilson, Hardman Earle, David Hodson, Directors, or very extensive Proprietors; and of the latter, Messrs. R. Stephenson, J. Locke, C. Vignoles, Civil Engineers; Mr. Dixon, Resident Engineer; Captain Moorsom, one of the Secretaries of the London and Birmingham Company; and Mr. Booth, the experienced and intelligent Secretary of the Liverpool and Manchester line.

Our first experiments were only tentative, with a view to try the instrument, but even in these much was very distinctly shown; when, for example, a train passed over, we could see clearly the operation of each wheel upon the rail, which, where these were well laid, and the joints and blocks secure, were only of a certain amount, but when the rails were unlevel, or other irregularities occurred, some lurch would take place, towards the middle or end of the train, which would strike the rail with sufficient force to throw up the index to nearly double its previous amount, indicating, of course, that it

had, in the case in question, sustained a deflection nearly double what it would have done with the same weight in a quiescent state.

These remarks, however, will be best made after stating, numerically, the results of our further observations.

Experiments made with a View to ascertain the Strain which a Load in rapid Motion produces upon the Rail over which it passes, in order to compare the same with the known Strain produced by an equal quiescent Load.

It may be proper to state in this place, that the Directors of the Grand Junction Railway Company having resolved that their rails should not weigh less than 60lbs per yard, and their Engineer, Mr. J. Locke, finding that with this weight of iron, or rather with bars of 62lbs. per yard, and with 3 feet bearing, there would be much more strength than the present, or any contemplated future practice would require, very properly took advantage of the superabundant

strength which the bar possessed to increase the distance, and thereby to reduce the number of the bearing blocks; but he would not, as a practical man, whose character might suffer by a failure, undertake to recommend, with the rail in question, a longer bearing than 3 feet 9 inches, which of course saved one-fifth of the usual number of blocks. But an experiment which it was unadvisable for an engineer to undertake, might be made without scruple by a private gentleman (no immediate mischief being to be apprehended;) and accordingly, at the suggestion of Hardman Earle, Esq. another block was dispensed with, and the bearings extended to 5 feet; several yards of this rail are thus laid in the main line near the Liverpool end, and the same with 3 feet 9 inches bearing, as also other experimental rails of different forms and weights. The rails at 3 feet 9 inches, and at 5 feet bearing, have been laid down since May last, without having sustained any observable injury; but it was desirable to examine their strength and stiffness, and the strains to which they are exposed, before such bearings could be safely

recommended for general adoption. All the other rails throughout the line are laid on 3 feet bearings, and vary in weight from 35lbs. to 60lbs. per yard.

The little instrument of Mr. King's was admirably suited to this inquiry, for by this the greatest deflection the bar sustains, from whatever cause it proceeded, was accurately registered, and by comparing this deflection with the experiments made on the same bar with quiescent loads, the effects due to velocity, and those proceeding from irregularities in the joints, &c. became known, at least in the aggregate, and this aggregate is of course the strain against which it is necessary to provide.

Experiments on the central Deflection of Railway Bars during the passage of a heavy Load at different Degrees of Speed; and on different Lengths of Bearings.

Our observations were commenced in and near the cutting at Wavertree-hill, in rock cutting,

the ground being as sound, and the bearings as firm, as in any part of the line.

The first trials were made on the Grand Junction Rail laid down in May last, on 3 feet 9 inches bearings. The weight of rail 62lbs. per yard. A deflectometer was accurately placed under each of four bearing lengths—one having been selected next the bearing end, the other three were middle lengths. The following were our recorded observations:—

First Experiment.

With the passage of the Speedwell engine and Train, at a medium velocity, or about 20 miles per hour: this showed—

Deflection of joint length		·0625 inch.	
Ditto	middle length	·0425	
Ditto	ditto	·0400	mean ·0408
Ditto	ditto	·0400	

Second Experiment.

With the Swiftsure engine, furnished for the experiments: weight on driving wheels, 5 tons 16 cwt.; velocity about 20 miles per hour.

Deflection of joint length		·0800 inch.	
Ditto	middle length	·0320	
Ditto	ditto	·0400	mean ·0380
Ditto	ditto	·0420	

Third Experiment.

The same engine, very slow :

Deflection of joint length		·040 inch.	
Ditto	middle length	·024	
Ditto	ditto	·025	mean ·027
Ditto	ditto	·032	

Fourth Experiment.

One trial, quite at rest ·040

The mean of the above three means is ·0353

To compare this with the mean deflection of such a bar, with a quiescent load, I may refer to my experiments on the same bars at Woolwich, forwarded for the purpose by the Directors of the Grand Junction line, (See Appendix,) by which it appears that the mean deflection per ton, at 33 inches clear bearing, was ·0050 ; consequently, for three tons, ·0150 ; and reducing this to the clear bearing of 45 — 3 = 42 inches, we

have as $33^3 : 42^3 :: \cdot0150 : \cdot0314$, the deflection with three tons at rest; and the mean of the preceding deflections in motion is ·0353, a close agreement, which shows, that when every thing is well fixed and secure, the deflection, and consequently the strain, is nearly the same, whether the load be in motion or at rest, and that each rail is only pressed with half the weight of one pair of wheels.

I ought to observe here, that Mr. Locke also made experiments on the same bars, by means of an hydraulic press, in Mr. Gray's yard, adjoining the Liverpool Station, which showed larger deflections per ton than the above; but on witnessing the performance of this engine, I am convinced it is not sufficiently accurate for the purpose of the smaller strains, although it may give pretty well the large and ultimate results. It is very satisfactory to me to be able to say, that since my published experiments were made, and since those were made on the Grand Junction Railway bars, the machine I employed in His Majesty's Dock Yard has been placed in charge of Peter Ewart, Esq., a gentleman well known

and respected by most of the parties interested in this inquiry. It was accordingly tested by him for the accuracy of its registers, (by an apparatus furnished by Messrs. Bramah, for the purpose,) and was found remarkably perfect and delicate in its action, registering, however, as when first erected, 3 per cent. below its actual power. Under these circumstances, I think it will be admitted that I am justified in using my own results for the comparison. I have no doubt of the skill and accuracy which Mr. Locke employed in the experiments ; but the machine itself does not possess sufficient accuracy for measuring the smaller strains.

It may be proper to explain the difference in the mode of registering in the above machines, and the cause of the superiority in that which I employed. This consists in the registering of its powers by a system of well-balanced levers at the end of the press bed, by which a pound, or rather a weight equal to $15\frac{1}{2}$ ounces, just balances a ton; and so accurate is this balance, that 1 ounce in the scale, or $\frac{1}{16}$th part of a ton weight or strain is perceptible, and 2 ounces, or

$\frac{1}{8}$th of a ton, quite obvious; and it is, from the nature of the operation, the same for the great and small strains, which can never be the case where the register is dependant, as in the other machine, on water pressure.

Experiments on the same Bars at Five Feet Bearing.

FIFTH EXPERIMENT—SWIFTSURE ENGINE.

Velocity about Twenty-two Miles.

		v.=22.	v.=22.	v.=22.
Deflection	middle length	·093	·077	·080
Ditto	joint length .	·083	·080	·123
Ditto	ditto .	·108	·143	·130
Ditto	middle length	·082	·070	·077

With greater Velocities.

		Speedwell.		Fury Train.
		v.=30	v.=32.	v.=23.
Deflection	middle length	·112	·122	·083
Ditto	joint length .	·080	·105	·085
Ditto	ditto .	·250	·120	·095
Ditto	middle length	·091	·115	·085

In obtaining a mean from these results, the deflections on the joint lengths are, as in the preceding case, rejected, being obviously in

excess. The mean of the rest, that is, of the central length, is ·089.

In my experiments at Woolwich, the deflection per ton at 33 inches' bearing being ·0050, or, for 3 tons, ·0150, we have, deducting 3 inches from 60, to obtain the clear bearing—

$$33^3 : 57^3 :: \cdot0150 : \cdot079,$$

while the mean determined by the deflectometer, as we have seen, is ·089.

Nothing can be expected much more satisfactory; as it is thus proved, *independently of any opinion*, that while the blocks and fixings are secure, the strain from a passing load is but little in excess of that from a quiescent load; whereas the effect on the joint ends amounts, from a mean of the preceding, to ·121, being in excess nearly 40 per cent. This, however, is not all strain, part being due to the looseness of the chair or block. (See Appendix.)

Experiments on the Lateral Deflection of Railway Bars.

Having ascertained the deflection of the bars in a vertical direction, it occurred to me that it

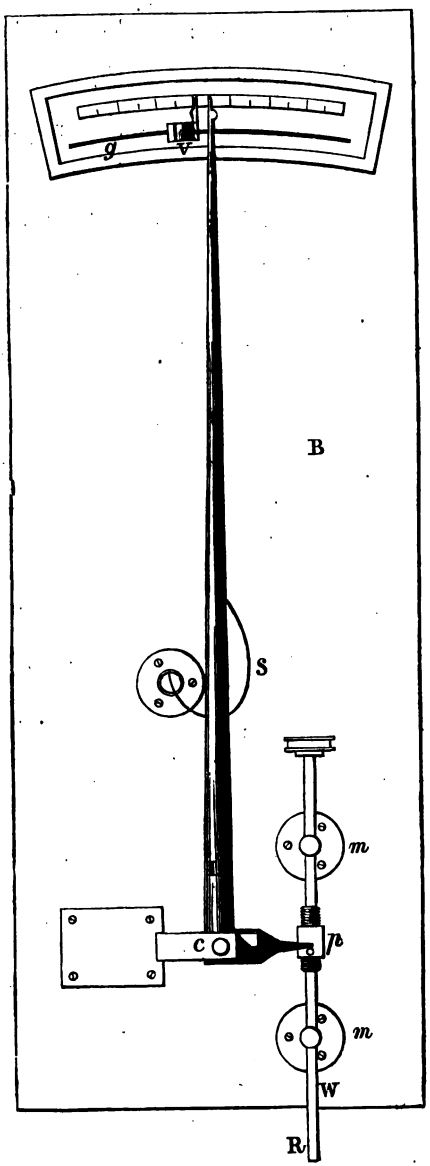
would be very desirable to ascertain to what extent the rails were deflected laterally on the outer sweeps of curves, in order that I might, if it should be found necessary, increase the thickness in the longer bearing rails, beyond what mere strength required, in order to counteract this necessarily greater strain. I accordingly wrote to T. W. Rathbone, Esq. to beg that he would have the goodness to get these experiments made, giving him a very rough sketch of the method I proposed to have employed; and I find myself again greatly indebted to Mr. King for working out my idea in a most satisfactory way, by the construction of the instrument described hereafter; as I am also to Mr. Edward Woods, for the detailed result of a series of experiments, given in the Appendix.

The whole of these experiments have a tendency to show, that the stress which the bars have to sustain in this direction is not such as to require to be more amply provided for than the increased thickness the bar must have, to meet the greater vertical strain due to the longer bearing. In other words, the additional strength given to the

bar, for the purpose of meeting the vertical strain, will be amply sufficient to meet and resist the lateral strain. It will therefore not be necessary, in proportioning the weights and sections of bars for different lengths of bearing, to attend to more than the vertical strength.

The following description of the instrument, and one set of experiments, will be sufficient for illustration.

Description of the Instrument.—In the annexed figure, L is a bent lever, turning on a centre *c;* V a vernier, sliding in the groove *g;* S a steel spring, to keep the short end of the lever in contact with the stud *p* to a wire sliding in the standards *m, m,* having an adjusting screw at *p,* to set the index to zero. The end R being now brought into contact with the rail, the stud *p,* on the passage of the engine, will press upon the short arm of the lever to the extent of its deflection, the amount of which, ten times multiplied, will be read on the scale or vernier at V.


g
B
S
m
c
p
m
W
R

The experiments were made on the Wigan Railway, with the engine "Experiment:" the rail parallel weighing 42lbs. per yard; the bearing distances, 3 feet.

The instrument being adjusted, the following results were obtained:—

	Deflection.	Velocity.	Direction of the engine.
Exp. 1	·047	8 miles per hour	Back.
2	·045	10 „	Forward.
3	·038	11 „	B.
4	·036	12 „	F.
5	·040	10 „	B.
6	·035	12 „	F.

The same experiment repeated, after the middle chair between two others was removed: the clear bearing now being 5 feet 10½ inches:—

	Deflection.	Velocity.	Direction of the engine.
Exp. 1	·070	4 miles per hour	Back.
2	·078	6 „	Forward.
3	·093	7 „	B.
4	·097	8 „	F.

As the velocities are not the same, except the first of the first series and the last of the second,

we can only make this one comparison, and by this the deflection appears to be about double, which is certainly less than calculation would lead us to expect; but the amount is so far within the elastic power of the iron, and the strength of the rail experimented on so inferior to what will probably be adopted, that I am quite satisfied no additional strength will be required to meet this strain.

The above experiments, and those on the same subject, given in the Appendix, were made by Mr. Edw. Woods and Mr. King, in the presence of T. W. Rathbone, Esq., Dr. S. Trail, of Edinburgh, and J. Reynolds, Esq. of Swansea.

Deductions.

It would be useless to interrupt the continuity of the Report, by introducing in this place all the observations that were made on the different rails, and I have therefore given them collectively in the Appendix, and shall only observe, referring to the vertical deflections, that the obvious deduction from them is, that with firm blocks, chairs well fixed, and with joints well made, the road itself being firm, the rail is only deflected at the greatest

velocity a little more than is due to a quiescent load equal to half the weight on the two wheels; but that in consequence of the imperfection of these parts, a strain is occasionally thrown on the rail which produces a deflection about double that which belongs to the load in question. This effect was frequently and obviously exhibited in the experiments with the trains. In many cases, the deflectometer showed only the common amount of deflection when the engine (by far the heaviest load) passed over; whereas, perhaps in the middle, or at the end of the train, a waggon would lurch over from some irregularities, and throw up the index to double its former amount. This effect was very particularly noticed by the Deputation, Directors, Proprietors, and other parties present. It follows, therefore, that till greater perfection can be obtained in railways, a strength of bar more than double that due to the mean strain must be provided. In my former Report, I have allowed 50 per cent. beyond the double, as a surplus; but from these experiments, it appears this allowance is in excess, and that from 10 to 20 per cent. beyond the double will be sufficient;

that is, for a 12 ton engine, as the weight is at present distributed, a strength of 7 tons would be an ample provision, and with greater accuracy of construction, such as the care now taken may be expected to ensure, a less strength would be sufficient; or rather, allowing the same strength, an engine of 14 or 16 tons might be passed over with the greatest confidence.

By referring to the observed results in the Appendix, it will be seen, that one rail is sometimes depressed by one wheel a quarter of an inch, while the other wheel is perhaps on a block; and immediately after the high wheel is depressed, and the lower wheel raised, giving thus a rocking motion to the carriages, the effect of which was rendered remarkably obvious by the little instrument employed. No doubt much of this is due to a want of parallelism in the bearing blocks; and therefore, as one step towards correction, I would recommend it to be made a special instruction, *that the blocks shall in every case be placed immediately opposite to each other,* which in parallel rails may always be effected without expense or inconvenience. Other corrections, however,

are necessary, which will be noticed in their proper places. I shall therefore, pursuing the present subject, proceed to draw such results as the foregoing experiments seem to justify. One of the most important of these is (being stated not as an opinion or supposition, but as an experimental fact), that with engines of 12 tons weight, and with velocities not exceeding 32 or 35 miles per hour, it is not necessary, even as railways have been hitherto constructed, to provide for a strain of more than 7 tons, which is allowing a surplus strength of 16 per cent. beyond the double of the mean strain.

This fact being established, it is clear that we may provide this strength for any length of bearing, by increasing the section of the bar proportionally as the distance of the props increase; but it may still be a question, which is the best length to adopt? or whether different lengths may not be advantageously employed, according to local circumstances? For example, in some places the stone blocks cost more than the iron rails they support, while in others, the blocks may be obtained at a cheap rate; therefore, in the

former case, if present cost only were considered, it might be advantageous to diminish the number of the blocks, and increase the weight of iron, and in the latter, to use less iron and increase the number of bearing blocks.

Still, however, there are limits which cannot be conveniently surpassed: if the blocks are too close, the requisite quantity of iron in the bar may be so small as to give a very unsatisfactory section; and on the other hand, if the lengths be too much extended, the weight of the bar must be made inconveniently great. Thus restricted, therefore, it will be useless to examine any distance of bearing less than three feet, or more than six; and in apportioning the quantity of metal for each length, regard must of course be had to the limits prescribed by practice, that is, we must only employ such sections as may be subject to no substantial practical objections; but with this condition, the form of section is unlimited.

The first limitation which practice enforces is, that whatever be the bearing length and weight of rails, the head ought to have the same certain weight.

It is not necessary to go far along the Liverpool and Manchester line to see that the heads of the original 35lbs. elliptical rails are far too small for the present weight of the engines, the outside flanch of the upper table being, in numerous instances, nearly separated from the central rib. The Dublin 45lbs. parallel rail, which has a broader and somewhat larger head, does not show the same defects: still, however, it is generally, I find, considered too small. The 50lbs. parallel plain T rail, and the Grand Junction rail, are perhaps the best proportioned heads in the line; their area of section, to an inch deep, occupying about $2\frac{1}{4}$ square inches. In the following calculations, therefore, I shall lay it down as a practical limit, that the head ought not to occupy less than 2·25 inches area, or which is nearly the same, not weigh less than 22·5lbs. per yard.

Another practical limit, in which I believe most engineers agree, is, that the depth of the rail ought in no case to be more than 5 inches.

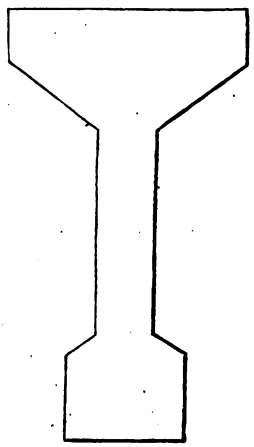
Abiding, therefore, by these conditions, I propose to compute the weight of iron per mile, on four lines of rails, preserving in all cases a constant

strength of 7 tons at the several bearing lengths of 3 feet, 3 feet 9 inches, 4 feet, 5 feet, and 6 feet, and the number of cubic feet of stone per mile required in each case; distributing the iron in each bar most economically for strength.

The lightest rail in the line, which appears to approach towards the required degree of strength, is the Dublin parallel rail, of 45lbs. per yard; but as the head is lighter than the present practice seems to point out as the best, I would increase this by $2\frac{1}{2}$ or 3lbs., and with a little addition to the rail itself, make the whole about 52lbs., which is, perhaps, the least weight that ought to be given to a rail on 3 feet bearings; and the best disposition of this weight, according to the solution of the problem on the principle of *maxima et minima*, regard being had to the practical limits above stated, is given in a subsequent page; and on similar principles, although not strictly following the minutia of the solution, have been arranged the proportions for the other bearings, the section at half size and the several particulars being as follow :—

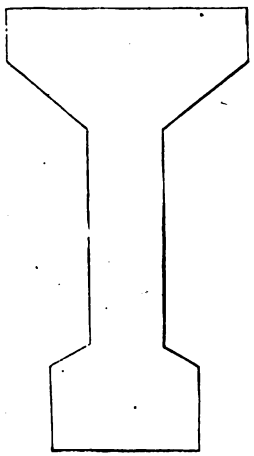
Section for a Three Feet Bearing.

ON A SCALE OF HALF THE LATERAL DIMENSIONS.



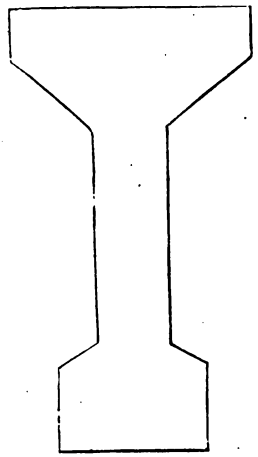
Head to 1 inch depth, 22·5 lbs. per yard; whole depth, 4½ inches.
Ditto bottom web, 1 inch.
Breadth ditto, 1·25 inch.
Thickness of middle rib, ·6 inch.
Whole weight, 51·4lbs. per yard.
Strength, 7 tons.
Deflection with 3 tons, ·024 inch.

Section for a Three Feet Nine Inch Bearing.



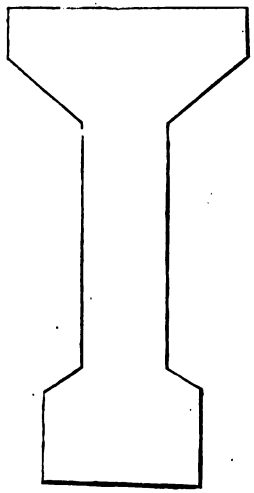
Head to 1 inch depth, 22·5 lbs. per yard.
Whole depth, 4⅜ inches.
Ditto of bottom web, 1 inch.
Breadth ditto, 1½ inch.
Thickness, middle rib, ·75 inch.
Whole weight, 58·8 lbs. per yard.
Strength, 7 tons.
Deflection with 3 tons, ·037 inch.

Section for a Four Feet Bearing.



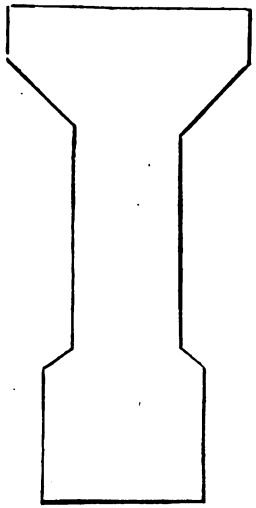
Head to 1 inch depth, 22·5 lbs. per yard.
Whole depth, 4¾ inches.
Ditto of bottom web, 1 inch.
Breadth of ditto, 1½ inch.
Thickness of middle rib, ·8 inch.
Whole weight, 61·2 lbs. per yard.
Strength, 7 tons.
Deflection with 3 tons, ·041 inch.

Section for a Five Feet Bearing.



Head to 1 inch depth, 22·5 lbs. per yard.
Whole depth, 5 inches.
Ditto of bottom web, 1⅛ inch.
Breadth of ditto, 1·66 inch.
Thickness of middle rib, ·85 inch.
Whole weight, 67·4 lbs. per yard.
Strength, 7 tons.
Deflection with 3 tons, ·064 inch.

Section for a Six Feet Bearing.



Head to 1 inch depth, 22·5 lb. per yard.
Whole depth, $5\frac{1}{10}$ inches.
Do. of bottom web, $1\frac{1}{2}$ inch.
Breadth ditto, 1·66 inch.
Thickness of the middle rib, $1\frac{1}{8}$ inch.
Whole weight, 79lbs. per on.
Strength, 7 tons.
Deflections with 3 tons, ·082 inch.

It will be seen by the above statement, that although I have preserved the same strength or resistance in each of the rails, the longer bearings are less stiff than the shorter; indeed, unless this increased deflection be allowed, all thoughts of greatly increasing the distance of the bearings must be given up; for, in order to preserve a proportional deflection, either the breadth of the rail must be so increased as to require a weight of iron altogether inadmissible, or the depth must be increased in the same proportion as the

length of bearing, which is impracticable. The deflections, however, of the longer bearings, although greater than the shorter, do not amount to a large quantity; the deflection * of several of the rails at present on the line being much greater, as may be seen by referring to the Appendix.

Assuming these dimensions, I have in the following table computed the number of tons of bar iron per mile, requisite for four lines of rail at different bearing distances, also the weight of the requisite number of chairs, and the number of cubic feet of stone, in order thereby to facilitate a comparison of the expense, or first outlay, under these several circumstances; but the price of stone being very variable, according to its quality and locality, the pecuniary amount is not attempted.

It may be proper to state, that the weights I have taken for the chairs is somewhat arbitrary; on weighing Mr. Stephenson's chairs, I find the joint chairs and pins to weigh 1 qr. or 28 lbs.,

* The effect of deflection is treated of in a subsequent page.

and the intermediate chairs and pins 24 lbs.; and as the depth in his rail, including his segmental piece, is the same as that I propose for the 3 feet bearing, I take this as my guide, and I have slightly increased the weight of both chairs as the rail becomes deeper. That is, I make for the

3 feet bearing-joint		chairs	28lbs.	Intermediate do.	24lbs.
3 feet 9 inches	do.	do.	30	do.	25
4 feet	do.	do.	30	do.	25
5 feet	do.	do.	33	do.	27
6 feet	do.	do.	33	do.	27

I was pretty generally informed, that by far the greater number of chairs that are broken, are destroyed in the wedging; and as no wedging is here intended, it is expected the above weights are sufficient.

In computing the quantity of stone, I have assumed the present sized blocks, of 4 cubic feet, sufficient at each distance, except the joint-blocks, which, as they ought certainly to be larger than the others, I have taken at 5 feet.

While the blocks preserve a perfect level, I am not aware that a joint-block, when the joint itself is perfect, has more to sustain than any other; but if one of them sink a little, the continuous rail

over an intermediate block has a much greater sustaining power as the load passes, than the discontinued rails at the joints. Moreover, as these have been hitherto made, a much greater shock is communicated to the support at the joints than to the other blocks; for both which reasons it becomes necessary that the joint-blocks should be greater, but to what extent it is difficult to say; I am, however, disposed to think one foot additional a sufficient allowance.

TABLE I.

Showing the Weights of Rails and Chairs requisite for forming a mile of Railway on four lines, accordingly as the bars are supported at greater or less distances.

Length of bearing.	Length of rail.	Weight of one rail.	Number of rails in four lines per mile.	Weight of rail per mile.	Number of joint chairs per mile.	Weight of joint chair and pins per mile.	Number of intermediate chairs per mile.	Weight of intermediate chairs and pins per mile.	Total weight of chairs and pins per mile.
Feet inches.	Feet.	lbs.		Tons.		Ton.		Tons.	Tons.
3 0	15	257	1408	161	1408	17½	5632	60⅓	78
3 9	15	294	1408	185	1408	19	4224	47¼	66¼
4 0	16	326	1320	192	1320	17¾	3960	44¼	62
5 0	15	337	1408	212	1408	20¾	2816	34	54¾
6 0	12	316	1760	248	1760	26	1760	21¼	47¼

TABLE II.

Showing the Number of Cubic Feet of Stone requisite for forming a mile of Railway in four lines, accordingly as the bars are supported at a greater or less distance.

Length of bearing.	Number of joint blocks in four lines per mile.	Number of cubic feet in joint blocks per mile.	Number of intermediate blocks in four lines per mile.	Number of cubic feet in the intermediate blocks per mile.	Total number of cubic feet of blocks per mile.	Expense of ballasting and laying per mile, as depending on the number of blocks.
Feet inches.						
3 0	1408	7040	5632	22,528	29,568	?
3 9	1408	7040	4224	16,896	23,936	?
4 0	1320	6600	3960	14,840	21,440	?
5 0	1408	7040	2816	11,264	18,304	?
6 0	1760	8800	1760	7,040	15,840	?

N.B. The above calculation for the stone rests on the assumption, that the same sized blocks are applicable at all distances of bearing. Some remarks on this subject will be found in a subsequent page.

In the preceding table I have only attempted to preserve the same strengths at all the different bearings; and I have observed that to preserve the same proportional deflection would require, if greatly extended, an inadmissible weight of iron in the rails. It may, however, be well to state that amount, which is as below; viz.

	Ft.	In.	Weight of Rail per yard.	Weight of Rail.	Weight per mile.
At	3	0	51·4 lbs.	257 lbs.	161 tons.
	3	9	67·5	337½	212
	4	0	72·0	384	226
	5	0	92·0	460	289
	6	0	22·5	490	385

If (as was, I believe, agreed upon by Mr. Stephenson and Mr. Locke) we take the present 50 lb. fish-bellied rail as the criterion for strength and proportional deflection, we must provide at least a strength of 8 tons, and not allow a greater slope than $\frac{\cdot 03}{\cdot 18}$. To insure these conditions the following weights and dimensions must be adopted, viz.

	Ft.	In.	Weight per yard.	Weight of Rail.	Weight per mile.
At	3	0	55·5 lbs.	277·5 lbs.	174½ tons.
	3	9	64	320	201
	4	0	66·7	356	209½
	5	0	75·8	379	238
	6	0	100	400	314

Such is, to the best of my judgment, an accurate statement of the weight of iron, and the quantity of stone, requisite to assure the same strength and security for the different bearing distances; and as far as mere present outlay is concerned, it may always be determined which is the most economical (or rather, which will cost the least money) when the price of the stone, the expense of the labour in laying, and the price of iron are given; but looking to future expenses, I must certainly prefer the larger bars, and longer bearings. Whatever deterioration is going on upon the iron, it is on its surface, and consequently will proceed no faster, or very little faster, in the larger bars than in the smaller; and therefore we have a right to assume, that the larger bars will last serviceable longer than the

smaller, although their strengths at the beginning are equal.

But this is not all the advantage that is claimed by some parties for the longer bearings; and I cannot but regret that so much time was wasted in the discussion of a question which was at all events of minor importance. It was contended, that as it was the practice, generally, on railway lines, to allow the blocks, while they were in a state of subsidence, to settle only a certain quantity before packing them, that this quantity being the same at long and short bearings, a central block sinking (say a quarter of an inch) would cause a less slope in long bearings than in the shorter; and thus, the slope being less, the action of the engine and carriages on the blocks would be less also, and to such an extent as to make it a consideration of economy, with regard to the maintenance of the road; that is, not only were the three blocks, for instance, in the five feet bearings, to perform their duty, as well as the five blocks in the three feet bearings, each block being of the same size, but they were to perform it better, in consequence of the lesser slope

produced by a central sinking block. Every one took part in this discussion, but as is generally the case with such questions, without convincing or being convinced. It occurred to me, therefore, to submit it to the test of observations, which our little instrument enabled us to do. It appears from the previous experiments, on 3 feet 9 inch, and 5 feet rails, that the deflection of the former was ·035, and of the latter, ·089; the slopes, therefore, were as $\frac{\cdot 035}{22\frac{1}{2}}$ to $\frac{\cdot 089}{30}$, or nearly as 1 to 2; consequently, according to the principle maintained in the argument, the blocks of the 5 feet bearings ought to have been more rocked than the 3 feet in that proportion; whereas, on trial, they were found to be of the two rather less affected, but as nearly equal as possible. The error, as I must consider it to be, unquestionably arose from assuming that the pressure of a body on an inclined plane was proportional to the height of the plane, or to the sine of the angle; whereas, it is as the cosine, and as the cosines of small angles are nearly constant, so also are the pressures of the weight upon the plane.*

* Another idea may have led to this false conception, *i. e.*

The manner in which these experiments were conducted was as follows :—a block being selected, a hole was drilled in it, and into this a strong cranked piece of iron was driven, and the tail of the deflectometer brought into contact with its lower edge. The effects of the passage of the engines were then read and registered, as in the case already described.

The first trials were made on four of the blocks of the 3 feet 9 inch bearings; one was what is called a hanging block, viz. one under which the ground has so much subsided as to leave the block just suspended by the rail; two of the blocks were sounded, and considered quite firm and solid, and another suspected not quite firm.

that the motion of the carriage "is naturally horizontal," whereby it may have been supposed, that it pressed harder on the plane, and of course on the prop, as the slope was greater; but this is not the case: the force which urges the body is tangential to the rail, and the pressure ought actually to be less as the slope is greater, as we found it to be. In my former Report, I have used an expression with respect to the elliptical rails which seems to imply something like this; but what is meant there is, that the change of direction of the tangent is more rapid in that part, and that this sudden change of direction was what produced the injurious effect spoken of.

Experiments with the Swiftsure; 3 feet 9 inches bearings.

		velocity =10 miles.	v.=16.	v.=20.	v.=30.
Hanging block	disturbance	·060	·090	·080	·085
Firm block	ditto	·010	·020	·022	·032
Ditto	ditto	·000	·012	·017	·032
Supposed not quite firm	ditto	·018	·028	·028	·032

Taking the mean of all but the hanging block, we obtain for the general disturbance ·021.

Experiments with the Swiftsure and two trains, on the blocks of the 5-feet bearings; blocks all firm.

Swiftsure.

		velocity=15	v.=15	v.=?	v.=?
Middle block, No. 1	disturbance	·014	·004	·004	·005
Joint ditto, No. 2	ditto	·024	·017	·012	·016
Middle ditto, No. 3	ditto	·017	·006	·004	·012
Middle ditto, No. 4	ditto	·030	·020	·018	·026

		Fury train.	*Orion train.*
Block, No. 1	disturbance	·012	·018
No. 2	ditto	·046	·028
No. 3	ditto	·004	·012
No. 4	ditto	·040	·032

Swiftsure.

		v.=medium.	v.=medium.
Block, No. 1	disturbance	·016	·008
No. 2	ditto	·036	·020
No. 3	ditto	·018	·010
No. 4	ditto	·023	·025

The mean of all these give a disturbance =·019, which differs very little from the former, but the greater slope, instead of exhibiting a greater, shows a less disturbance than the smaller slope; we may, however, consider them as equal, the difference being so extremely small, as not to be of any very definitive amount in experiments of this kind.

At all events the results tend to prove that the suppositious saving to be effected by reducing the amount of slope is not borne out by these experiments. I ought perhaps to observe, that in the first instance, some experiments were made with the same view as the above, on which the disturbance was measured, by driving in a broad chiseled edged piece of iron between the chair and block, projecting beyond the latter to meet

the deflectometer, which rather favoured the hypothesis in question; but it was admitted by all present, that they probably involved the motion of the chairs with that of the block, and were therefore by general consent rejected before any comparison was made, those above detailed having been made the following morning, were substituted for them.

Having, I hope, thus satisfactorily disposed of this side of the question, by admitting, for the sake of the argument, that the three blocks would not sink more than the five, let us now examine how far this admission is justifiable.

It is asserted in one report, that whatever the number of blocks may be, each block is pressed with, or has to sustain only the same weight during the passage of the train over it, and, therefore, whether on 3 feet bearings, or 5 feet, the sinking of the blocks will go on at the same rate; while others contend that, with the present distance of the wheels, the whole weight of an engine may fall on three blocks only in the 5 feet bearings, which would be distributed over five blocks in the 3 feet bearings; and, therefore,

although at the moment of the passage of a wheel over a block, that block is no more pressed in the one case than the other, it has, upon the whole, more pressure, or the effect of a greater number of blows to sustain in a given time when there are fewer, than when there are more, supports.

It seems to be impossible to deny this position, and I cannot doubt for a moment if rails upon a new ground or embankments were partly laid on 3 feet bearings, and partly on 5 feet bearings, the blocks being of the same size, that it would be found that the blocks in the latter case would sink faster than in the former, till the consolidations were fully effected; after which, I have little doubt the 5 feet bearing-blocks would be as efficient as the 3 feet, and that they would very soon become so in cuttings where the substrata are already well compressed. Another argument I have heard advanced, on the opposite side, is by assimilating the blocks of a rail to the piers of a bridge, which require to be broader as the number of piers are less, but this does not, I think, apply well to this question.

In a bridge, the weight of structure is nearly every thing, the passing load being inconsiderable; whereas in a railway the load constitutes the principal weight to be resisted.

The conclusion to which I am brought, as to the relative expense of maintenance per block in 5 feet and 3 feet bearings, or, more generally, in long and short bearings, after well weighing all these points, is, first, that in embankments, and where there is a soft sub-soil, the expense would be greater at first with the long bearings than with the short, but that it would ultimately become the same, although certainly never less; and, secondly, that on rocky, or very solid bottoms, the expense would be very nearly the same from first to last.

Such is my unbiased opinion; it is, however, but an opinion; and I do think it would be very desirable to submit the question, if possible, to experiment on an embankment. Would it not be worth the trouble to lay down on the embankment at Kensal Green, a certain length of the Grand Junction rails, at 3 and 5 feet bearings,

and to observe minutely the effect on each? The locomotion and train, I think, pass here seventy times a day, which would, in a very short time, decide the question, as far as embankments are concerned; and for the rest, I do not think there is any reasonable cause for doubt.

On the best Form of Rail.

In the sections given in a preceding page for Rails at different lengths of bearings, it will be seen that I have confined the breadth of the lower web to $1\frac{1}{2}$, or, at most, to $1\frac{2}{3}$, inches, and this has been done, although I am well aware that, to extend the breadth of the lower web, and to reduce its depth, would theoretically give the strongest rail; in fact, that the double T is, on paper, a stronger rail than the deep and less broad flanched rail, but I am quite convinced it is not so in practice. The lower web comes no other way into use than as it is brought into a state of tension by the action of the centre rib; and although the fibres of the lower web lying

immediately below the centre rib are brought into action by it, and that these fibres excite a similar action laterally in those immediately contiguous to them, and these again to the next, and so on, yet in a ductile metal, like malleable iron, this lateral effect is soon lost; so that the extreme fibres of the extended lower flanch become inefficient.

The fact is, this particular form of rail was proposed with a view to a certain advantage it was supposed to possess, viz. that it might be turned when the upper table had been worn down, but this has been shown in my former report to be impracticable; and not fulfilling this condition, while in other respects it is disadvantageous, it should be at once rejected; I know it is said it may still be turned and used in side rails; but I reply, wherever it is used, it will be strongest if not turned. Again, it is stated, that both sides being alike, the rail-layers may select the side that fits best; but it would surely be better to have the rails made so uniform that no such choice was requisite. Again, it gives a broad bearing, in which, however, I see

no advantage when carried to excess. And, lastly, it admits of the rail being fixed by a wooden key or wedge; but is it not better, if possible, to avoid the wedge altogether? In fact, I can see no advantage this form of rail possesses, to compensate for its actual and obvious defects.

The proportions I have shown in the preceding diagrams, which resemble nearly the form of rail to which the prize was awarded, is, I am persuaded, the strongest and best. It being of course understood that these diagrams give only angular outlines, the salient and re-entering angles of which may be softened down or fortified according to the taste or other considerations of the engineer.

To convince Mr. Locke, and some other gentlemen of the weakness of the double T form, I had one of the rails taken up, and $\frac{1}{2}$ an inch cut away on each side from the lower flanch, reducing its breadth at the point of greatest strain, that is, in the middle of the bar, to $1\frac{1}{2}$ instead of $2\frac{1}{2}$ inches. It was then put into the press, and the strains brought on as usual, under

the superintendence of Mr. Edward Woods and Mr. John Gray; Mr. Locke himself being obliged to leave just at the time the experiment was in progress.

Mr. Rathborn, Mr. Edward Cropper, and myself, were also present, and the result was, that the bar thus mutilated showed greater strength than the mean strength which Mr. Locke found to belong to it when whole. Now, although I am ready to grant that the bar was actually weakened, and that this apparent anomaly is attributable to the imperfection of the press already pointed out, yet, on the other hand, it must be admitted that it could, with such a result, have lost but little of its strength, and that the iron thus abstracted, *viz.* nearly $\frac{1}{8}$ of the whole section, if judiciously introduced elsewhere, would undoubtedly give a much stronger rail.

Mr. Woods' report of this experiment is given in the Appendix.

On the Form of Chairs, and the means of securing the Rail to the Chair.

This is a delicate subject to approach, after so much has been done and written respecting it; and I know of only one qualification I possess, beyond that of common observation, to enable me to form a judgment upon it; which is, that I have no proposition of my own to recommend. I examined with every necessary attention all the different chairs, keys, filling-up pieces, &c. on the Liverpool and Manchester line, and must say that no one, in my estimation, is so simple, nor so well adapted to preserve the bar steady, as that made to receive the plain T rail. Nor, in my opinion, would any other have ever been thought of, if it had not been for the introduction of the lower web. The question therefore is, How are we to retain the advantages of the lower web, without losing the simplicity of lodgement due to the plain T rail? Now, a method of effecting this is proposed by Mr. Sinclair, in his recent Report, which consists in having a recess cut in the rolls, so that at the ends of the bar, and at every

point of bearing, the rail shall form a plain rib equal in thickness to the breadth of the lower flanch, that is,

Fig. 1.

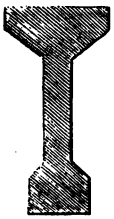


Fig. 2.

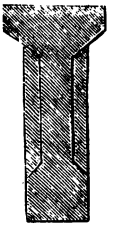


Fig. 3.

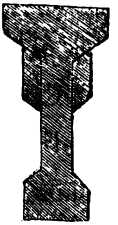


fig. 1. being the general section of the rail; about 3 inches at each bearing point would assume the plain T form shown in fig. 2, or, if more simple, to roll, the form fig. 3.

On inquiring of those best able to judge, I find it admitted that this proposition is practicable. I do therefore think, that we have in such a rail and chair all the good qualities that can be desired. 1st. We have all the simplicity and steadiness of lodgement due to the plain T rail. 2d. We retain all the advantages of the lower web. 3d. We have all the breadth of bearing that can be serviceable; and 4th, In case a central block sinks, we have a much

stiffer double bearing length than could be otherwise obtained.

This last, I conceive to be a decided advantage, although, amongst other doctrines I have heard on this subject, one has been, that the small neck of the fish-bellied rail gives it less strength, and thereby enables the rail to bend and follow the block in its downward progress into the ground; and this was considered an advantage; but, I must say, if it be one, I am unable to see in what it consists.

I have only at present spoken of the lateral support of the rail in the chair; but it is necessary to prevent the rail rising in the chair, or rather, it is necessary to prevent the rail quitting the bottom of the chair when the latter sinks; and I do not think this can be more simply, nor more efficiently performed than with the present chair and pin proposed by Mr. R. Stephenson, omitting, however, his segmental piece.

In my former Report, having no idea it was possible to effect what Mr. Sinclair now proposes, I considered that the *whole* chair for the joint ends would have been useful; but Mr.

Sinclair's present proposition offers, in my mind, such decided advantages, that I consider the whole chair to be rendered quite unnecessary, or rather, that each chair thus becomes a whole one.

It is proper here that I should notice also a provision which Mr. Locke has made in the bed of his chair, to prevent the rising up of the end of the rail, while the rail itself is submitted to deflection by the passage of a load; which I consider very useful. It is obvious that if the bed of the chair be left, as it commonly is, quite square; when the rail is deflected by a load in the middle, the whole bearing is brought upon the inside edge of the chair, and the short remaining part of the joint end is thrown up with such great force (although the motion is not much) as to render it impossible to restrain it. But what cannot be restrained by force is here judiciously prevented from occurring by giving a very slightly curved figure to the bottom of the chair, whereby the inside contact falls as the deflection proceeds, instead of allowing the end to rise; and certainly such form of chair-bed I

should strongly recommend, whatever chair may be adopted. The curvature required is, of course, very small, being scarcely perceptible to the eye, but it avoids a great strain upon the chair itself. And the other great and irresistible strain from contraction and extension, which is brought on when every thing is keyed tight, is also easily provided against, or will soon provide for itself, by the mode of fixing recommended; that is, the small hole made by the pin in the rail may be a little enlarged, or it will soon enlarge itself sufficiently to admit the contraction and expansion to proceed without injury, and without reducing its holding power on the rail itself; and that this action does take place in the rails thus laid down may be seen by examination, the ends of the pins and the holes on the rails being both slightly polished, and the latter a little elongated. One of the pins in each rail also being rather harder driven than the rest, will answer the other object pointed out in my former Report: viz. to furnish a fixed point towards which the contraction may take place from each end of the bar. This was the sug

gestion of Mr. Woodhouse, which I omitted to notice in my former paper.

In some of Mr. Stephenson's chairs the pins are chissel-ended, instead of pointed. Of course, either the one or the other may be used that is found to answer best.

On the Formation of the Joints.

On carefully examining the joints of the rails on the Liverpool and Manchester line, I am disposed to estimate that about one in six of the plain butt joints are as perfect as can well be desired, and that another one in six are as bad as bad workmanship and negligence can make them; the remaining two-thirds varying in character between these two extremes. These circumstances naturally lead to the question:—

On what does the goodness of the joints consist? and the answer is plain.

1st. On the uniformity of size and figure in the tranverse section of the rail.

2d. On the straightness and evenness of the bar, longitudinally.

3d. On the squareness of the ends of the rail to the line of its length. And,

4th. On the uniformity of size and figure in the opening of the chair.

There can be no question, if these points could be perfectly attained, the joints would be perfect also; and though perfection is not to be had, still a great approach towards it may be made with proper care, and would be made, if enforced in the condition of the contract, at a very inconsiderable charge. The practical genius and talent our iron masters have at their command, stimulated by the large amount of the sum to be expended, would, if conditions were enforced, lead to the contrivance of simple means of effecting these objects within very close limits; and, I will venture to say, that nothing like perfection in railways will be obtained till such conditions are made and complied with. It is, of course, understood that the means of producing the requisite degree of accuracy will rest with the iron master, but the methods of gauging, or otherwise ascertaining how far the contract has been complied with, and the allowable

amount of deviation, will be the business of the Company.

I will not here undertake to prescribe either the limits of deviation, or the means of testing or guaging, which will both be best settled by the Company's engineer, after duly weighing all the circumstances of the case; but will merely add, that in Government contracts for shot, shells, &c. very little deviation is allowed, and yet it is seldom found necessary to reject any of the articles sent in.

In the smaller shells, which are still considerably larger than the opening in a railway chair, and unquestionably much more difficult to cast, not more than a deviation of $\frac{1}{30}$th of an inch is allowed, and I can see no reason why the railway chairs, and the end of the rails, should not be submitted to at least as close a guage. To enforce this accuracy may, perhaps, incur some present charge, but do not the wear and tear of the rails and engines incur a much larger constant expense of maintenance? I am sure it is unnecessary for me to urge this point upon those proprietors who witnessed, during the experi-

ments, the concussion on the rail exhibited by the deflectometer, which, of course, produced a like concussion on the engine and carriages. The whole of these were, doubtless, due to irregularities, of which the want of parallelism of the blocks and bad joints were the principal. Some persons present attributed them in part to flat places in the wheel; but if there are flat places in the circumference of the wheel, to what are these attributable but to bad joints? To be convinced of this we have only to consider what must be the effect of a blow on a wheel supporting a load of 3 tons, and moving with a velocity of 30 or 32 miles per hour, when such a body meets the end of a rail rising $\frac{1}{8}$, or, perhaps, nearly $\frac{1}{4}$ of an inch above another; or when the joints are so open as to allow the wheel to fall from one upon the other, with all the impetus due to such velocity.

In order to arrive at some estimate of this effect, a bad or open joint was selected, the deflectometer applied to the block, and the shock measured by the instrument. The rail was then taken up and relaid, so as to make the joint as

close as usual, leaving the opening at the other end, and the effect was again taken, when it was found that the bad joint increased the force of concussion full 50 per cent.; that is, the engine had to sustain a shock from this circumstance one-half at least greater than was due to a very common joint, and probably double what it would have had to sustain at a good one.

The experiment above alluded to was our last, and was made by Mr. Edward Cropper and myself, with the Swiftsure engine. The following are the results:—

	Bad joint.		Replaced joint.	
Disturbance	·043	.....	·032	great speed.
Do.	·030	.....	·016	
Do.	·031	.....	·022	
Do.	·023	.....	·015	
Mean disturbances	·032	Mean	·021	

Seeing, then, the obvious injury produced by bad joints, and the impossibility of having good ones, without a strict uniformity in the opening

of the chair and in the size of the end, and bearing part of the rail, as well as in the perfect straightness of the bar, and the squareness of its end;—seeing, further, that all these conditions may be insured at an inconsiderable charge for examination, when the articles are received, it will remain for the Directors to decide how far it will be advisable to adopt these suggestions.

I have not spoken of the half-lapped joint, because I think if the butt joints were well made, the half-lap would be unnecessary; for, as I have already observed, there are perhaps about one-sixth of the present butt joints on the rail as good as any lapped joints could be made, and even much better than they would probably be made unless cut by machinery, which, in the large bars, the Directors will most probably adopt, would be attended with a great expense without yielding an adequate advantage.

On the Fixing the Chair to the Block.

This question ought to be considered under two points of view; that is to say, simplicity of fixing and removing a chair, in case of necessity, and the firmness of the hold which it gives. In my former Report I recommended, for security of holding, a method which had been proposed for drilling a hole quite through the stone, and using a large-headed bolt, except that for reasons assigned in the Report, I proposed to countersink the stone below. I find, however, that it is a very prevailing opinion amongst those who ought to know, that this method has been tried some years back and found to be inefficient, and that it was ultimately rejected by its original inventor. I find also that, in general, the opinion of those who have considerable practice is, that the method now most commonly employed with a wooden plug and iron pin is, upon the whole, efficient and satisfactory; and under these circumstances, I feel myself bound to recommend the latter.

Summary.

I have in the course of the preceding pages replied to every point, which by the resolution already referred to, I was requested to examine and to report upon. In so doing I have thought it right to explain the several principles and experiments from which I have drawn my conclusions; and these being thus disconnected, it may be well to state them here collectively and isolated from other matter. In this form they will stand thus:—

1st. I am of opinion, that as far as is consistent with the amount of the first outlay, it is desirable to increase the weight or section of the rails, and to decrease proportionally the number of bearing blocks.

2d. That in cuttings and other places furnishing a good firm bearing, the present size of blocks is sufficient; viz. allowing for the intermediate blocks four feet, and for joint blocks five feet, while the bearing length does not exceed five feet; but that on embankments they will probably require to be proportionally

increased in size. But I recommend this to be put to the test of actual experiment.

3d. I am of opinion that the cost of maintenance will, in the former case, after a short time, be in proportion to the reduced number of blocks, but certainly not less.

4th. I consider the double and equal flanched rail to be inferior, in strength and convenience of fixing, to that which is described and modified to suit different distances, in a preceding page.

5th. I consider Mr. Sinclair's proposition for rendering the rail plain at its points of bearing, to be in every respect recommendable.

6th. I am of opinion the form of chair, and method of fixing the rail in the chair, proposed by Mr. Stephenson, is as simple and efficient (adopting the plan of rolling of Mr. Sinclair) as can be desired.

7th. Yielding, as I am always ready to do, to practical opinions, when they are found pretty generally to agree, I am disposed to think the present mode of fixing the chairs to the blocks, with a wooden plug and iron pin, is, from its simplicity and convenience, the most recommendable.

Lastly. I am strongly convinced that no change or modification of form will produce any essential improvement, till greater uniformity be enforced in the figure and dimensions of the rails and chairs, and greater attention paid to the parallelism of the blocks, and to a proper adjustment of the distances of the ends of the rails from each other to allow for expansion and contraction.

In now concluding this Report, I think it my duty to state, that should it be found to contain any valuable facts or information, it is indebted for them to the facilities and conveniences with which the Deputation were supplied by the Directors of the Liverpool and Manchester line, to whom also I feel great obligation for many personal accommodations and attention. And I am sure that I am only acting in accordance with the feelings of my coadjutors, Isaac Solly, and Thomas Tooke, Esqrs., who formed the London Deputation, in expressing our warm acknowledgments to Theodore W. Rathborn, Esq. for the hearty and hospitable manner in which he entertained us during the greater part of the time

we were engaged in the experiments and investigation, which, I have great reason to hope, will be found to have led to some useful results, and to which we shall never recur without the most gratifying recollections of the bounteous and cheerful hospitality of Allerton Priory.

P. S. The foregoing is my original Report; on the printing of which some other matter was added, but afterwards cancelled, and in consequence there will be found an interruption of the paging, which being however thus noticed, will be no inconvenience to the reader.

THEORETICAL INVESTIGATIONS

ON THE EFFECT OF DEFLECTION.

To determine the Influence of the Deflection of an Elastic Bar to the Motion of a Body passing over it, the Bar being supported at its two extremities.

1. Let A C B represent an elastic bar, supported at its middle point and loaded at its extremities with two equal weights, w, w. Then the deflection of the two ends will be exactly the same as that of the same bar supported at its ends and loaded with a weight $2w$ at its middle point.

Fig. 1.

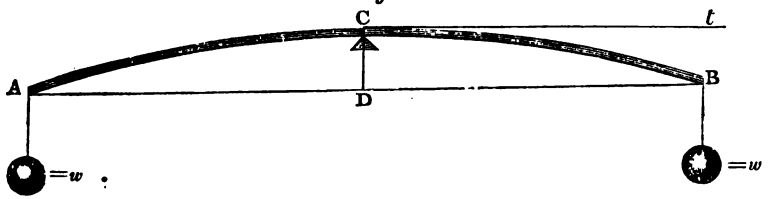
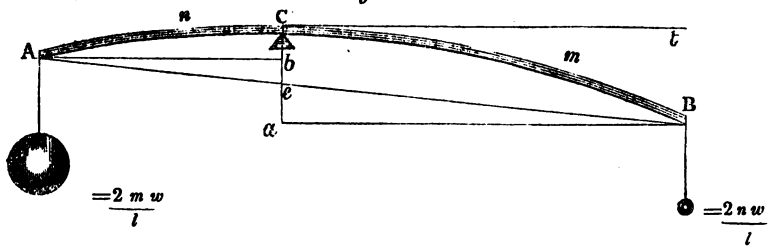


Fig. 2.



2. Let A C B, *Fig.* 2, be the same bar supported at any point C, dividing the beam into two lengths m, n, and loaded at B by a weight $\frac{2\,n\,w}{l}$, and at A by a weight $\frac{2\,m\,w}{l}$ (l being the whole length), so that the beam may be still in equilibrio on the support C, and the sum of the two weights equal to $2\,w$, as before. Then C b will be the deflection of the point A, and C a of the point B, C e being a mean deflection, as referred to the oblique line A B, and this deflection C e will be the same as if the beam was supported at A and B in a horizontal line, and loaded at C with a weight $2\,w$, the deflections being considered as very small in comparison with the length.

In *Fig.* 1, let the element of deflection at C be Δ, then the whole deflection, being as the element of deflection into the square of the length, we may represent C $a = \delta$ by $\frac{1}{4}\,l^2\Delta$.

But the element of deflection in the same beam is as the strain : and the strain at C in *Fig.* 2, is to that in *Fig.* 1 as $m\,n : \frac{1}{4}\,l^2$. Therefore, in *Fig.* 2,

the element of deflection $\Delta' = \frac{4\,m\,n}{l^2}\,\Delta$

and the deflection C $a = \frac{4\,m^3\,n}{l^2}\,\Delta = \delta'$

the deflection C $b = \frac{4\,m\,n^3}{l^2}\,\Delta = \delta''$

and $b\,a = \frac{4\,m\,n\,(m^2-n^2)}{l^2}\,\Delta = \delta' - \delta''$

consequently, the sine of the inclination, or of the angle A B a $= \frac{4\,m\,n\,(m^2-n^2)}{l^3}$

And this is precisely the inclination the tangent C t would have, if the beam were turned about C till A B became horizontal, and therefore the same as the tangent C t would have, if the beam were supported at its ends, and loaded at C with a weight 2 w; and it is this inclination which forms the impediment to the motion of the body along the plain face of the bar.

To find the point where this inclination is the greatest, we have—

$$\begin{cases} m + n = l \\ m\,n\,(m^2-n^2) = \text{a max.} \end{cases}$$

or, $m(l-m)(2lm-l^2)$ a max.

or, $-2lm^3+3l^2m^2-l^3m$ a max.

whence, $-6lm^2+6l^2m-l^3=0$

$$m^2-lm=-\tfrac{1}{6}l^2$$

$$m=\tfrac{1}{2}l(1\pm\sqrt{\tfrac{1}{3}})$$

$$n=\tfrac{1}{2}l(1\mp\sqrt{\tfrac{1}{3}})$$

When m and n have their values, the inclination of the tangent is the greatest, and consequently at that point the resistance to the motion is the greatest. It is shown that the sine of the angle of inclination is expressed generally by

$$\frac{4mn(m^2-n^2)}{l^3}$$

Calling $l=1$, this is $\frac{2}{3}\times\sqrt{\frac{1}{3}}=\cdot384$.

Now the inclination of a plane of half the length of the bar, viz. $\frac{1}{2}l$, whose altitude is equal to the central deflection, viz. $\frac{1}{4}l^2\Delta-$ (with which this case is frequently but erroneously confounded) would when $l=1$ be proportional to $\frac{\frac{1}{4}l^2}{\frac{1}{2}l}=\cdot5$. That is, the greatest resistance a heavy load experiences in consequence of the deflection of the bar over which it passes, is to the constant resistance it would experience in ascending an inclined plane, whose height is equal to the

central deflection, as ·384 to ·50, or nearly as 3 to 4. The former, moreover, acts only for an instant, and begins and terminates in zero, while the other remains constant throughout.

To compare the sum of all the resistances in the two cases, let us consider still $l = 1$, then the general expression for the resistance at any point, viz.

$$\frac{4\,m\,n\,(m^2-n^2)}{l^3}$$

becomes $4\,(-2\,m^3 + 3\,m^2 - m)$

and this multiplied by the differential of m, gives

$$4\,(-2\,m^3 + 3\,m^2 - m)\,d\,m$$

the integral of which between the values $m = \frac{1}{2}$ and $m = 1$, is $\frac{1}{8}$.

While the sum of all the constant resistances ·5 for the half length $= \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$.

That is, the sum of all the variable resistances to a load by the deflection of the bar over which it passes, is exactly half the resistance the load would experience in ascending a plane of the same half length, and whose height is equal to the central deflection of the same bar.

Now the resistance on such a plain, the central deflection being δ, which is to be considered the

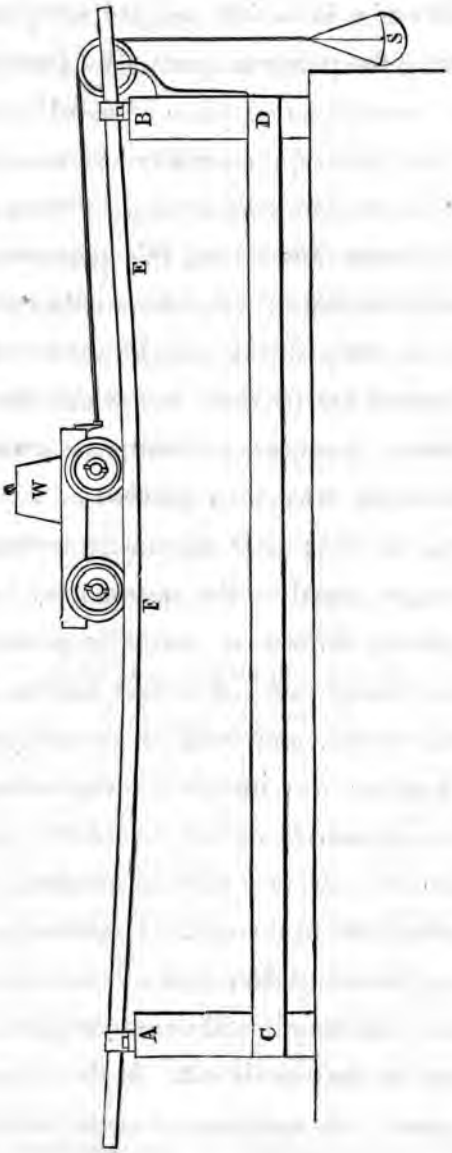
height of the plane, its length being $\frac{1}{2}\,l$, is $\frac{2\,\delta}{l}$, consequently the resistance of a bar only deflected to the same extent will be $\frac{\delta}{l}$.

It will be understood that this is the resistance to the ascent of the body from the middle of the bar up to the prop; and if, as was assumed in the Parliamentary Committee on the question of the Great Western Railway, as much power was gained in the descent as was lost in the ascent, the odds would be made all even, and the deflection of the bar would be no impediment; but that assumption is altogether erroneous, both in theory and practice. In fact, the gain from descent is so exceedingly small in such short planes as we are here considering, that it may be wholly rejected; so that in a plane supposed perfectly horizontal, the retardation, or additional resistance to the carriages, caused by the deflection of the bar, will be equivalent to the carriage being carried up a plane of half the whole length on a slope equal to $\frac{\delta}{l}$, the other half being horizontal, or, which is the same, on one entire ascending plane, whose slope is $\frac{\delta}{2\,l}$ where l is the distance between the props, and δ the central deflection. Having,

thus, the resistance due to deflection estimated on a continually rising plane, the resistance per ton becomes known, and consequently the exact numerical increase of engine power which is necessary to overcome that resistance. Computing in this way, it appears that the effect of deflection on the several bars whose sections are given in page 30, *et seq.* produce resistances equivalent to planes of the following slopes; viz.

Bearing distances. Ft.	In.	Deflections.	Equivalent planes.	Increase power per ton.
3	0	·024	1 in 3000	·75lb.
3	9	·037	1 in 2432	·92lb.
4	0	·041	1 in 2341	·95lb.
5	0	·064	1 in 1875	1·2lb.
6	0	··082	1 in 1756	1·3lb.

These being important considerations in the economy of Railways, and feeling that what is perfectly satisfactory to a mathematician, cannot be equally so to persons not in the habit of following such trains of reasoning, I had a little model made, representing one length of rail, the distance of the supports being 30 inches; the bars are drawn steel, $\frac{1}{4}$ inch by $\frac{1}{8}$; the load with the carriage weighs 134 ounces, and the deflection with that weight is nearly half an inch. The model is represented in the annexed diagram,


S
B
D
E
W
F
A
C

with the scale, in which weights are placed for illustrating the points in question. From A to B was laid a well-planed piece of wood, on which, in the first instance, the railway bars were secured at their proper parallel distance. The end of the model A being now raised, this plane was made to be truly horizontal; weights were then gradually put into the scale till that weight was found which just balanced the friction, and which was found to be exactly 5 ounces, including the scale.

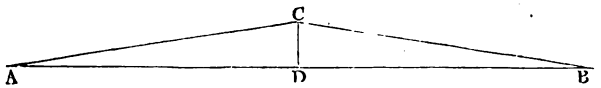
The model was then placed in its natural position, the base C D accurately levelled, and the carriage placed on the unsupported bars, the weight being thrown as nearly as possible over the front wheels only; 5 ounces due to friction were introduced, and weights gradually added; as each ounce was introduced the carriage advanced, and with 16 ounces it rose over the point E, where the resistance was the greatest, and was then accelerated to the end. E, according to the preceding investigation, was a little beyond the half of the half length, and the same was distinctly indicated by the experiment. At the lowest point of the curve the resistance was the same as on

the horizontal plane, as it was also at the end B, which are both likewise consistent with the investigation.

The bars were now removed, and the plane already mentioned placed from A to B, inclining so that the bars passed exactly through the point F, when it was found that the weight necessary to balance the carriage and friction was $19\frac{1}{2}$ ounces. The greatest resistance, therefore, on the deflected bars was to the resistance on this plane as $(16 - 5)$ to $(19\frac{1}{2} - 5)$, or as 11 to $14\frac{1}{2}$, which is also very closely approximative to what is given by the theory. The only doubt, therefore, which can remain, is how far I ought to reject as inconsiderable any increase of power on the descending side. This point cannot be met experimentally, and I am therefore obliged here to depend only on demonstration. The case certainly involves no difficulty of conception to those acquainted with theoretical mechanics, but the question having been seen in a different light by a gentleman of considerable scientific eminence, I should have been glad to have exhibited the effect experimentally; but as the

whole turns upon velocity, this is, of course, impossible.

It was my intention to have given in this place a sketch of the subject of gradients, but as it would be thought, perhaps, somewhat irrelevant to the principal object of this Report, and since to examine it in detail, and to compare it with known results, would occupy more space than I can well bestow upon it, I shall reserve this investigation for some future opportunity, and only explain here the principle according to which it appears to me the subject ought to be treated.



When a load has been raised up an inclined plane from B to C, the duty performed by the engine has been to overcome the friction, and to raise the whole load to the height D C. Now, on the descending plane C A, the load having a tendency to descend, except so far as it may be retarded or retained by friction, this tendency may be employed in assisting to overcome the friction, and thus to return back more or less of

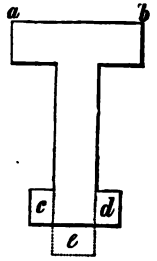
the power expended to raise it. But the quantity of returned power will depend upon the time of descent, and can never exceed what gravity itself would generate in the load, if free during the time of descent: that is, when a body is *urged* down a plane by a force beyond that of gravity, we must only attribute to the latter the effect or motion it would be capable of impressing on the load, if free, on the same plane, and during the same time.

This being admitted, it follows that very little aid will be derived from gravity during the passage of the load along half the length of a bar, or half the distance between two supports, the time being only about $\frac{1}{20}$ of a second, and the slope not more than 1 in 2000 or 3000. I have therefore in the preceding investigations rejected it altogether.

Of the Section of greatest Strength.

The question, Which is the figure of greatest strength? has, like most others connected with

the subject of railways, given rise to directly opposite opinions. While one party contend that the strongest form is that which has the lowest and broadest flanch, others maintain, that if the flanch was wholly removed, and the metal placed so as to continue the centre rib to a greater depth, a considerable additional strength



would be obtained. The argument advanced in support of the latter doctrine is this: Suppose *a b c d* to denote a rail with a double flanch, the lower one being marked *c* and *d*, it is maintained, if these parts were removed, and placed in continuation of the centre rib, as shown at *e*, that these fibres being now placed further from the neutral axis than in their former position, they would become more effective. So far this is true, but then the part of the centre rib between *c* and *d* would become less effective; because, in the first form, this part is amongst the lower fibres, which are all exerting their full tension of 10 tons, while in the second form, the parts between *c* and *d* are no longer found amongst the lower fibres,

and it is the lower ones only in which this full tension can be exerted.

It is clear, therefore, that this is a question which comes immediately under the class of *maxima et minima*, the solution of which is as follows; viz.

Given the area of section of a railway bar below the neutral axis, to find the dimensions of the lower flanch, so that the strength shall be a maximum; the breadth of the middle rib, and the depth of the lower flanch being also given.

Referring to the annexed figure, or to p. 57 of my former Report; let the whole of the sectional area below

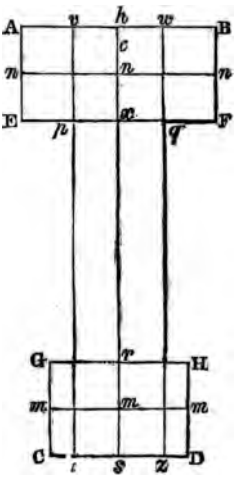
$n\,n$ $= a$

the breadth of rib $p\,q$ $= b$

the depth $n\,s$ $= d'$

the depth of lower flanch $r\,s$ $= e$

the tension of the lower fibre $= t$



1. To find first the expression for the strength of the middle rib; take any variable distance x,

then $d' : t : x : \frac{tx}{d'}$ = tension of fibre at x.

Multiply by the distance x, and breadth b, and we have for the sum of all the resistances

$$\int \frac{t}{d} b x^2 dx = \frac{t b}{3 d'} x^3;$$

this when $x = d'$ becomes $\frac{1}{3} d'^2 b t$.

2. To find an expression for the strength of the lower flanch: Let the breadth $= b'$; any distance from $n n = x$.

then $d' : t :: x : \frac{tx}{d'}$ = tension of fibre at x.

Multiply by the distance x, and breadth b'.

We have for the sum of all the resistances,

$$\int \frac{t}{d'} b' x^2 dx.$$

This taken between the values $x = d'$ and $x = d' - e$, gives:

Resistance—

$$\frac{3 d' e^2 - 3 d' e^2 + e^3}{3 d'} b' t = (d' e - e^2 + \frac{e^3}{3 d'}) b' t.$$

Therefore, the resistance of the rib and lower flanch is, $\frac{1}{3} d'^2 b t + (d' e - e^2 + \frac{e^3}{3 d'}) b' t.$

And the question is, to determine what value must be given to d', that this expression may be a maximum.

To effect this it is only necessary to consider d' as variable, to denote it by x, to find the value of the dependent quantity b' in terms of x, to substitute these quantities in the preceding expression, and to make its differential equal to zero.

Now, since the depth of the middle rib is x, and breadth b, the area is $b\,x$, and consequently the area of the lower flanch $= a - b\,x$, and its depth being e, its breadth $= \frac{a-b\,x}{e}$, that is, $b' = \frac{a-b\,x}{e}$.

Substituting, therefore, $\frac{a}{e} - \frac{b}{e}x$ for b', and x for d' in the preceding expression, it becomes, rejecting t, which is common,

$$\frac{1}{3}\,b\,x^2 + (e\,x - e^2 + \frac{e^3}{3\,x})\,(\frac{a}{e} - \frac{b}{e}\,x) = \text{a max.}$$

Or,

$$d(\frac{1}{3}\,b\,x^2) + d(e\,x - e^2 + \frac{e^3}{3\,x}).(\frac{a}{e} - \frac{b}{e}x) + d(\frac{a}{e} - \frac{b}{e}x).$$

$$(e\,x - e^2 + \frac{e^3}{3\,x}) = 0, \text{ or}$$

$$\frac{2}{3}\,b\,x\,dx.$$

$$+ (e - \frac{e^3}{3\,x^2}).\,(\frac{a}{e} - \frac{b}{e}x)\,d\,x.$$

$$-\frac{b}{e}(ex-e^2+\frac{e^3}{3x})\,dx.=0$$

Or,

$$\frac{2}{3}bx+(e-\frac{e^3}{3x^2}).(\frac{a}{e}-\frac{b}{e}x)-\frac{b}{e}(ex-e^2+\frac{e^3}{3x})=0.$$

Or,

$$\frac{2}{3}bx+a-bx-\frac{e^2a}{3x^2}+\frac{e^2b}{3x}-bx+be-\frac{be^2}{3x}=0.$$

Reducing every term to the denominator $3x^2$, and rejecting it, this becomes

$$2bx^3+3ax^2-3bx^3-e^2a+be^2x-3bx^3+$$

$$3ebx^2-be^2x=0. \text{ or}$$

$$-4bx^3+(3a+3eb)x^2-e^2a=0. \text{ or}$$

$$x^3-\frac{3(a+eb)x^2}{4b}=\frac{-e^2a}{4b}$$

$$x^3-\tfrac{3}{4}(\frac{a+eb}{b})x^2=\frac{-e^2a}{4b}$$

From which x may be determined for any given values of a, b, and e.

As an example, take a rail, in which the middle rib is ·78 inch, or b=·78, as given in Example 2, p. 64 of my former Report, to find what flanch must be given, and the corresponding depth of rail to produce the maximum strength.

The rail being 4½ inches below the neutral

axis, and its breadth b=·78, its area is ·78 × 4½ =3·51=a; and it is required to distribute this area so as to produce a rail of maximum strength, the depth of the proposed flanch being 1 inch. Substituting a=3·51, b=·78, e=1, the foregoing equation becomes

$$x^3 - 4{\cdot}11\,x = -1{\cdot}12.$$

Whence x=4·04 the depth of the rail required.

Now, 4·04 × ·78=3·15 area middle rib.

$$a - b\,x = 3{\cdot}51 - 3{\cdot}15 = {\cdot}36 = b'.$$

Or, ·36 the area of the lower flanch, which is also its breadth, its depth being 1.

The strongest rail, therefore, of this weight whose breadth is ·78, is that whose depth is 4·04 inches, and the breadth of the lower flanch, including the middle rib, is ·78+·36=1·14 inch.

It will be observed, that in this solution, for the sake of simplification, the strength or resistance of the head, which is very little, has been neglected. Nor is the resistance transferred to the centre of compression; but it is obvious, that when the strength is a maximum estimated from the neutral axis, it must be so also when referred to the centre of compression, or very nearly so.

Strength of the Rail computed.

The whole depth $4{\cdot}54 = hs$, $ns = 4{\cdot}04$, $pq = {\cdot}78$.

Head $\left\{\begin{matrix}(2 - {\cdot}78) \times 10 = 12{\cdot}2 \\ (4{\cdot}54 - \frac{1}{2}) \times 12 = 48{\cdot}48\end{matrix}\right\} = {\cdot}25$

Middle Rib $\dfrac{4{\cdot}54 \times 4{\cdot}04 \times {\cdot}78 \times 10}{3} = 47{\cdot}69$

Lower Flanch
$$\left\{\begin{matrix}(4{\cdot}54 - 1) \times {\cdot}36 \times 10 = 12{\cdot}7 \\ 12\,(4{\cdot}54 - 1)^2 + 4 \times \overline{3{\cdot}54} = 171{\cdot}6 \\ 171{\cdot}6 - \overline{2 \times 3{\cdot}54} + 1 = 165{\cdot}6\end{matrix}\right.$$

$171{\cdot}6 : 165{\cdot}6 : 12{\cdot}7 : = 12{\cdot}25$

$60{\cdot}19$

4

$33)\,240{\cdot}76$

$7{\cdot}3$ tons nearly.

If we take the area the same 3·51, with the flanch 1 inch deep, and the rib ·6 thick, the general equation becomes

$$x^3 - 5{\cdot}137\,x^2 = -1{\cdot}46$$

This gives $x = 5$ very nearly.

So that the depth assumed in Exam. 3, p. 64, in my former Report, is for the thickness ·6 of an inch the rail of maximum strength.

APPENDIX,

CONTAINING

THOSE EXPERIMENTS WHICH ARE REFERRED TO, BUT NOT INSERTED IN THE REPORT.

Experiments made at Woolwich to ascertain the Strength and Stiffness of the Parallel Rail, with Double Flanch, for the North Union Railway.

Weight per yard, 62lbs.; area of section, 6 inches; depth, 4½ inches.

Results obtained from three single Experiments.

Weight.	Deflection by Index.	Deflection for each ton.	Weight.	Deflection by Index.	Deflection for each ton.	Weight.	Deflection by Index.	Deflection for each ton.
1	·028		1	·035		1	·009	
2	·031	·003	2	·039	·004	2	·016	·007
3	·036	·005	3	·044	·005	3	·020	·004
4	·038	·002	4	·048	·004	4	·029	·009
5	·043	·005	5	·054	·006	5	·033	·004
6	·046	·003	6	·059	·005	6	·034	·001
7	·050	·004	7	·064	·005	7	·038	·004
8	·055	·005	8	·069	·005	8	·042	·004
9	·060	·005	9	·076	·007	9	·046	·004
10	·066	·006	10	·082	·006	10	·050	·004
11	·074	·008	11	·086	·004	11	·055	·005
12	·084	·010	12	·096	·010	12	·066	·011
Mean deflection, with 11 tons,	·051			·055			·051	

Results obtained from the mean of three Experiments.

Weight.	Deflection by Index.	Deflection for each ton.	Weight.	Deflection by Index.	Deflection for each ton.	Weight.	Deflection by Index.	Deflection for each ton.
1	·027		1	·021		1	·018	
2	·031	·004	2	·026	·005	2	·024	·006
3	·036	·005	3	·031	·005	3	·028	·004
4	·039	·003	4	·036	·005	4	·033	·005
5	·044	·005	5	·041	·005	5	·037	·004
6	·048	·004	6	·044	·003	6	·040	·003
7	·052	·004	7	·048	·004	7	·044	·004
8	·057	·005	8	·053	·005	8	·048	·004
9	·063	·006	9	·059	·006	9	·053	·005
10	·070	·007	10	·064	·005	10	·059	·006
11	·077	·007	11	·071	·007	11	·067	·008
12	·087	·010	12	·081	·010	12	·077	·010
Mean deflection, with 11 tons	·055			·055			·054	

Computed mean deflection, ·055.

Experiments made on the Deflections of different Rails and Blocks on the Liverpool and Manchester Railway, referred to, but not given in the preceding Report.

DUBLIN AND KINGSTON PARALLEL RAIL.

Weight 45lbs. per yard; with a lower web; bearing distance 3 feet; fixed by vertical keys; depth, $3\frac{1}{8}$.

Swiftsure Engine.

	Deflections in parts of inches.						Means.
Joint length	·120	·120	·105	·167*	·177*	·105	·114
Ditto	·120	·084	·098	·090	·080	·098	
Middle length	·125	·110	·130	·130	·156*	·130*	·120
Ditto	·110	·103	·108	·112	·120	·108	

The deflections marked with an asterisk are remarkable instances of the effect of the lurching of the engine and carriages, spoken of in the Report as amounting to nearly double the smaller and more natural deflections.

In the above experiments the blocks were sounded, and found firm; the fixings also appear to have been secure at the time of making the experiment; but generally the vertical keys used with this rail, require, according to the report of the workmen, incessant attention.

MR. STEPHENSON'S FISH BELLIED RAIL.

Weight 43½lbs. per yard; bearings 3 feet, fixed by iron keys on the side; great depth, 4½, less ditto, 3¼.

Swiftsure Engine.

		Deflections.				
1	Joint length	·032	·040	·038	·027	·045
2	Ditto	·070	·170	·068	·130	·077
3	Middle length	·125	·130	·130	·170	·093
4	Joint length	·030	·025	·030	·028	·056

The blocks of Nos. 2 and 3 were loose.

The mean of the other deflections is ·034, but we have no experiments to compare with.

The same Experiments repeated on four other Rails: velocities not recorded.

Middle length	·105	·135	·100	·150	
Ditto	·035	·050	·047	·053	Mean ·062
Ditto	·075	·075	·070	·085	
Ditto	·065	·060	·070	·060	

The great discrepance between the means in these two sets of experiments is very remarkable; I am quite unable to explain the cause from any fact I am acquainted with.

THE RAILS ON THE ST. HELEN'S LINE.

Parallel, with lower bead; weight, 43lbs. per yard; bearings, 3 feet.

Swiftsure Engine.

	Deflections.			
Joint length	·110	·092	·115	·095
Middle ditto	·060	·075	·100	·068
Joint ditto	·070	·080	·148	·135
Middle ditto	·082	·045	·063	·045

Mean deflection of joint length, 105; of middle lengths, ·067.

MR. BOOTH'S NEW RAIL.

Parallel, with equal upper and lower flanch; weight, 60lbs. per yard; depth, 4 inches; bearing distance, 3 feet.

Swiftsure Engine.

	Deflections.		
Middle length	·066	·062	·066
Joint ditto	·038	·084	·050
Ditto ditto	·100	·042	·144 lurch.
Middle ditto	·040	·052	·044

The deflectometers were removed from the above two joint lengths; the other two remained the same.

Middle length	·052	·064	·064
New joint ditto	·048	·064	·042
Ditto ditto	·074	·082	·050
Middle ditto	·056	·060	·054

Mean of the four middle lengths, ·056.

Experiments on the Disturbance of the Blocks of Mr. Booth's Rail.

Swiftsure Engine.

1st Block,	supposed not firm,	·018	·028	·018	·023
2d ditto	ditto	·036	·040	·036	·032
3d	firm	·022	·013	·014	·011
4th	ditto	·024	·020	·027	·023

Mean of the first and last two, which appear to have been firm, gives the disturbance, ·020.

It appears by the experiments on the Grand Junction Rail, given in the Report, that

At the 3 feet 9 inches bearing the disturbance was	·021
At the 5 feet bearings	·019
And Mr. Booth's, as above, 3 feet bearings	·020

Showing that the disturbance of the block is but little dependent on the amount of deflection, or length of bearing, on a well consolidated base.

Parallel Plain T Rail.—Huyton. Plane.

Weight, 50lbs. per yard ; bearing, 3 feet ; laid down ten months ; depth, 3½ inches.

		Vesta Train.	Sampson Train.	
1st	Middle length . .	·088	·070	
2d	ditto . .	·072	·066	Mean ·067
3d	ditto . .	·052	·044	
4th	ditto . .	·068	·080	

Swiftsure Engine.

	Slow.	Velocity 12	V. 15.	
1st.	·064	·084	·082	
2d.	·065	·080	·082	Mean ·072
3d.	·048	·060	·060	
4th.	·072	·080	·086	

General Mean, ·0695.

ON CHAT MOSS.

Mr. R. Stephenson's Fish-bellied Rail and Chair.

Weight, 44lbs. per yard, 3 feet bearing on wooden sleepers. The four deflectometers were here applied to two blocks and two rails, but not adjacent, and the disturbance on the blocks and rails observed together as below :—

Swiftsure Engine.

	Deflections.				Means.
1 Block . .	·058	·060	·060	·060	·059
2 Middle Rail	·176	·178	·200	·198	·188
3 Block . .	·030	·028	·040	·032	·032
4 Joint Block .	·152	·160	·160	·170	·160

Experiments repeated.

The rails and blocks being now selected, so as to have one rail between the two blocks, and the other adjacent, the results were :—

	Deflections.					Means.
1 Block . .	·018	·018	·018	·022	·023	·019
2 Rail between	·178	·195	·190	·194	·196	·191
3 Block . .	·050	·056	·060	·056	·060	·056
4 Rail adjacent	·136	·124	·154	·130	·124	·134

These results again, as in the other fish-bellied rails, are very anomalous. In the present instance, we may suppose a great deal is to be attributed to their peculiar situation, as the whole road trembled under our feet as the engine passed; but still the great excess of deflection of the rail, beyond that of the disturbance shown by the block, is very unaccountable, although some of it may be due to the working of the segmental piece in this particular chair. Still, however, after every allowance, I must think there are obvious indications of the rails being much more strained in such a situation as this, than on a good bottom; and should this be verified by further observations, it would certainly be advisable in future, in such cases, to strengthen the rails, either by enlarging them beyond the dimensions given in the other part of the line, or, which would amount to the same, preserving the dimensions, and reducing the bearing distance.

The speeds, in the two last set of experiments, varied from 15 to about 21 miles per hour.

"*Experiments made on the Wigan Railroad, 10th September, 1835, on the Lateral Deflection of Railway Bars. By Mr. Edw. Woods.*

"The rails are of the parallel form, weight 42lbs. per yard; bearings, 3 feet.

"1*st Series.*—On the curve near the junction to the Liverpool and Manchester Railway.

Curve = 2 feet 4 inches per chain.
= to a radius of 622 yards.

"The outer rail of the curve $1\frac{3}{8}$ inches higher than the inner rail, to counteract the centrifugal force of the trains.

"Deflection (lateral) of an outside rail, 1 ft. 6 in. from the bearing. Engine, *Experiment.*

	Def. in inches.		
No. 1	·040	10 miles per hour.	
2	·024	8	ditto.
3	·026	8	ditto.
4	·022	14	ditto.
5	·007	10	ditto.

"2*d Series.*—Another rail on the outside of the curve, same engine, &c. as before.

	Deflect. inches.	Miles per hour.	
No. 1	·000	13	F
2	·018	10	B
3	·000	9	F
4	·023	9	B
5	·017	11	F
6	·060	8	B
7	·031	10	F
8	·055	9	B
9	·042	12	F
10	·086	11	B

" N. B.—The letters F and B denote whether the engine was working forwards or backwards.

" 3*d Series.*—With a rail exactly opposite that of the second series, viz. on the inner rail of the curve.

" In this and in all other experiments, the deflection was measured outwards from the centre of the road.

" In this instance the defleetion seemed to arise solely from the wedge-like action of the conical tyre on the wheels, as some paint which had been smeared for a few yards on the inner side of the rail had not been wiped off; shewing that the flanch had not come into contact with the rail. Engine, the *Experiment.*

	Deflect. inches.	Miles per hour.	
No. 1	·030	8	B
2	·030	9	F
3	·040	9	B
4	·040	10	F
5	·030	4	B
6	·000	2	F
7	·037	3	B
8	·002	2	F
9	·033	3	B
10	·001	2	F
11	·006	6	"Jupiter," with a coach train.

"4*th and* 5*th Series* are given in the Report.

"6*th Series.*—With a rail on the straight road. Engine, the *Experiment.*

	Deflect. inches.	Miles per hour.	
No. 1	·010	8	B
2	·010	14	F
3	·010	15	B
4	·007	10	F

"7*th Series.*—Another rail near the same place. Engine, the *Experiment;* weight of working wheels, 5 tons 15 cwt. 1 qr.

	Deflect. inches.	Miles per hour.	
No. 1	·032	16	B
2	·032	12	F
3	·020	13	B
4	·010	5	F
5	·008	4	B
6	·010	4	F
7	·046	25	B
8	·020	18	F

(Signed) "EDWARD WOODS."

The following is Mr. Edward Wood's statement of the experiment on the Grand Junction Rail, referred to in page 34 of the Report. By taking the difference between the deflection at 5 and 10 tons, we find a remainder ·027, and this divided by 5 gives ·0054 for the mean deflection per ton, which agrees nearly with my deflection on the same bar whole; but it is considerably less than that given in Mr. Locke's former experiments; it would therefore appear that the bar shewed as much, or more, strength or stiffness in this case as when whole; but I have already stated the probable reason of the discrepance.

"*Experiment on the Deflection of a* 62*lbs. Grand Junction Rail, with a* 3*-feet bearing under the Hydraulic Press.*

"This rail was taken up from the north line of railway in Olive Mount Cut, where it had been in use for about three months, supported on blocks at intervals of 5 feet. In the central point between the two bearings (viz. 18 inches from each bearing), a portion of the lower web, for the space

of 1½ inch, was chiselled away, so as to reduce its thickness or width (transverse to the length of the rail) to exactly 1½ inch. The following are the results obtained, when submitted to the action of the press :—

" In the pressure recorded, 1 ton = 2240lbs.

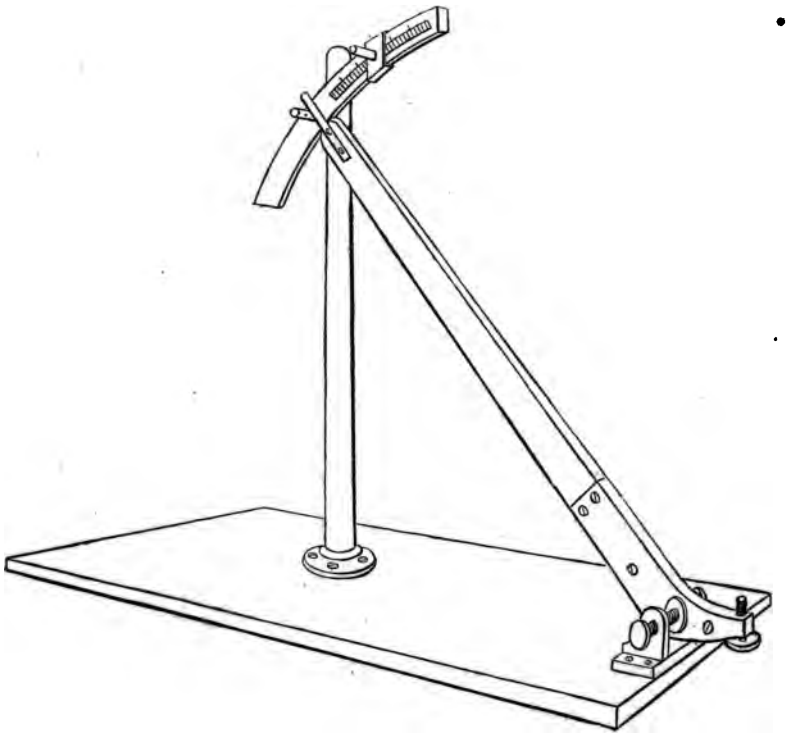
Tons pressure.	Deflec. inches.	Remarks.
5	·015	
7	·028	
8	·030	
9	·035	
10	·042	permanent set ·000 inch.
11	·051	ditto ·002
12	·066	ditto ·015
13	·083	ditto ·036

(Signed) " EDWARD WOODS."

Improved Deflectometer.

One inconvenience attending the use of the original deflectometer was, the index being so near the ground as to render it very troublesome to measure the result. This has been obviated in another form of the instrument, as made by Mr. W. Gilbert, 148, Leadenhall-street. The register is here by a sliding vernier on an arc,

the latter also being raised, the result may be read with great ease and convenience. The upright standard carrying the arc is a brass tube, which fits tightly over a brass pin on the base board. It may, therefore, be easily removed, and the whole packed very close for convenience of carriage, as shewn in the following figure.



Woolwich, Oct. 29, 1835.

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